

NEW HORIZONS
= IN
FOOD PRESERVATION

TECHNICAL LIBRARY
U. S. ARMY
NATICK LABORATORIES
NATICK, MASS.

by Reuben Pomerantz*

Atoms Strike The Cereal Industry

RSB-33

THE PRODUCTION AND handling of subsistence is one of our nation's largest industries, amounting in annual sales to about 60 billion dollars, with 165 million Americans spending daily more than 35 million dollars in some 500,000 retail food stores. No industry faces a greater challenge than that of bringing the world's food supplies economically and efficiently to your dining table. But economy and efficiency must wage a constant and heretofore losing battle against waste.

Although great strides have been made in the last few decades toward improving methods of food preservation, several factors have dictated a continuous and seemingly endless search to add a "third dimension" to our two principal processes—heating and refrigeration. Among these factors are food losses caused by spoilage and insect infestation, the quest for improved quality, and our population increase of $1\frac{1}{2}\%$ per annum. Current methods of preservation enable the food processor to fulfill his daily commitments, but fall far short of our needs. Nationwide annual losses in fruits, vegetables, and livestock equal the production of 32 million acres, and losses caused by rodents and insects in stored food total 6 million dollars. By 1975 we shall have a production deficit of 90 million acres unless we can reduce food spoilage substantially.

A Third Dimension for Food Processing

Atomic energy may well provide this sought-for "third dimension": ionizing radiation adapted to the

food industry. For the consumer, the arrival of the atom on the farm may well herald cheaper and better foods, of improved quality and stability through the food processor's contributions.

Contrary to many optimistic predictions which have appeared in the press, the age of radiation processing of food is not yet here. However, possibilities for the future are certainly encouraging and appear to warrant the intensive research program now being sponsored by the Department of the Army, under the over-all supervision of the Quartermaster Food and Container Institute for the Armed Forces, Chicago, Illinois.

There is nothing mysterious concerning the use of atomic energy to preserve foods, nor is the basic principle a new one. Soon after X-rays had been discovered by Roentgen in 1895 it was shown that they could penetrate matter with ease and could bring about death of living cells. The properties of X-rays and other forms of ionizing radiation have been widely exploited over the years, but their application was not focused on the food industry until the close of World War II, when radioactive by-products of the Atomic Energy Commission's program became available and high-energy particle accelerators were developed.

Nature of the Radiation Process

The revolutionary process of preservation by radiation employs nuclear energy instead of heat to destroy microorganisms which promote food decomposition and spoilage. Since in this process there is only a minute rise in temperature in the

treated product during the short exposure time of seconds or minutes, this method is often called "cold preservation."

Although the ultimate destructive effect is still not clearly defined, it is currently believed that nuclear rays strike microorganisms much in the same manner as a fast-moving projectile strikes its target. These nuclear "bullets" either kill bacteria outright or so disrupt the vital functions of proteinaceous cells that they can no longer reproduce (Fig. 1). In addition to this direct action, the so-called "indirect" effect of ionizing radiation may eventually destroy microorganisms by ionizing the surrounding medium.

Source of Radiation Energy

Of the numerous forms of electromagnetic radiations and particulate beams available to the nuclear physicist, cathode rays and X-rays or gamma radiations are the only types of paramount importance to the food industry.

Cathode rays are electron beams produced by man-made generators, the simplest of which consists essentially of an evacuated tube with a cathode (negative terminal) at one end and an anode (positive terminal) on the other. Millions of volts are needed to energize electrons for irradiation of foods, and thus the common terminology is Mev (million electron volts). Several types of electron accelerators appear to be feasible for radiation processing, the principal ones being the Van de Graaff generator, the resonant transformer (Fig. 2), the capacitron, and the traveling wave linear accelerator (Fig. 3). Commercial production

*Captain, Quartermaster Food & Container Institute for the Armed Forces, Chicago, Illinois.

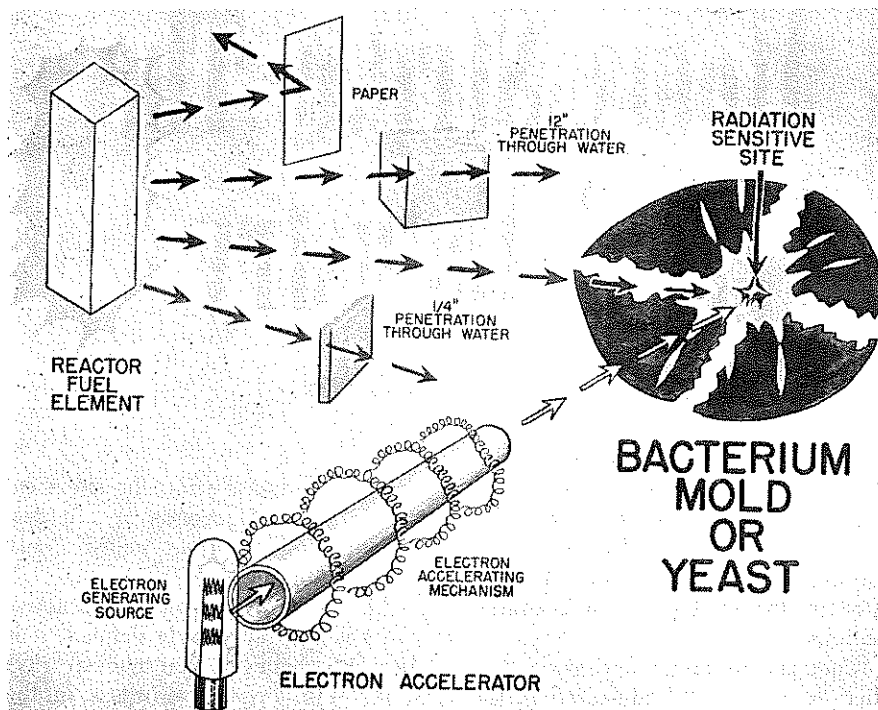


Fig. 1. Action of ionizing radiation on microorganisms.

units will require high power output, and the linear accelerator appears to hold the greatest potential for use at the high energy levels

which are essential for significant penetration.

The major disadvantage of the electron generator is its relatively low

penetration. Depth of penetration is a function of electron energy and target density. For unit density material a 1-Mev machine will penetrate, with uniform dose on both external surfaces, approximately $\frac{1}{8}$ inch. A double pass or cross firing will extend this distance about $2\frac{1}{2}$ times or a total of about 0.3 inch per Mev.

X-Ray Machines. X-rays can be produced by bombarding suitable heavy metal targets with electrons. Although penetration is greater by this method, there is tremendous loss of energy in the form of heat at the target surface. Because of this energy loss in converting the electron beam to X-rays, and reduced utilization per given volume because of its high penetration, the beam power of an X-ray machine must be about five times as great as for the same machine using electrons directly.

Gamma Rays. Gamma rays have the same physical characteristics as X-rays; they are not produced by machines but are emitted from the atomic nucleus during radioactive decay. Their absorption in matter is exponential and thus not finite but,

Fig. 2. 1-Mev. General Electric resonant transformer.

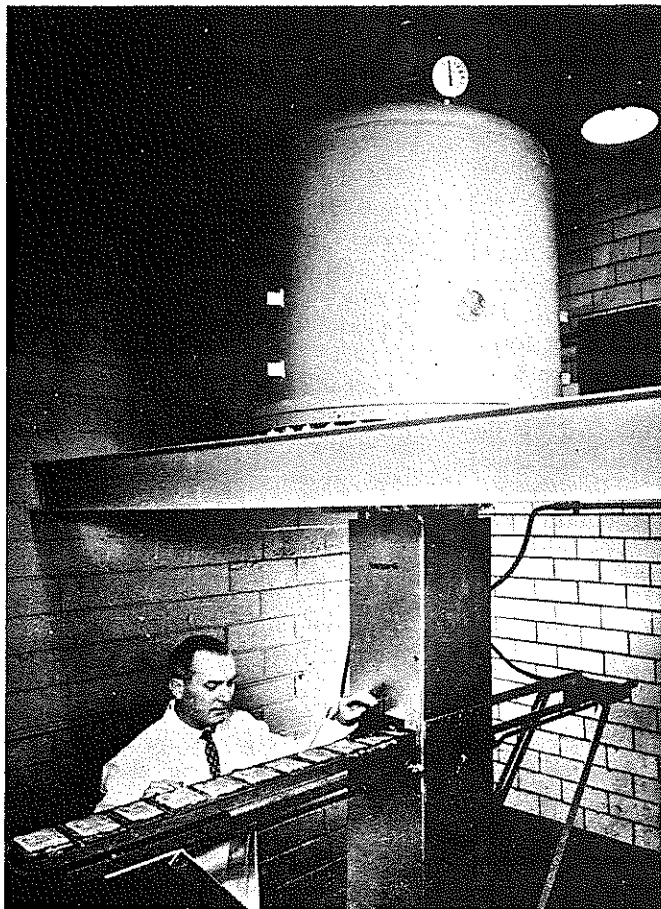


Fig. 3. 50-Mev. high-voltage Engineering Corp. Linear Accelerator

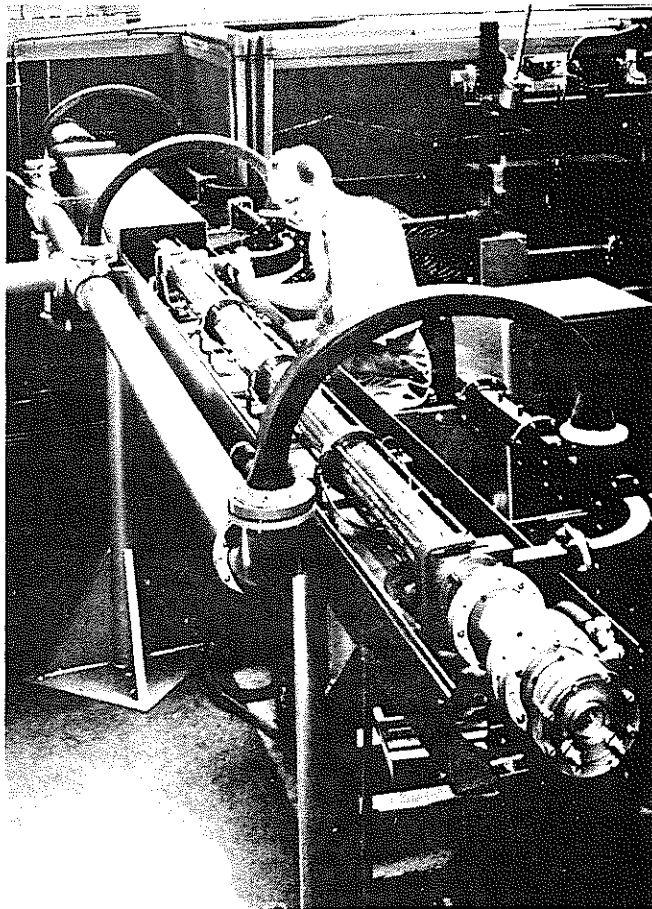


Fig. 4. Dosage distribution vs. penetration in flour by 3-Mev. gamma and cathode rays.

as in the case of electrons, is dependent upon the energy of the incident rays and the density of the material being treated. The half-thickness of H_2O (the amount of water required to reduce the initial intensity of a 1-Mev photon of X energy to one-half its initial intensity) is about 5 inches (Fig. 4).

Commercial radiation processing will require very large sources of gamma radiation, which nuclear reactors may in the future provide. Several forms of gamma radiation can currently be considered as feasible for future food processing:

1. Spent fuel elements—used fuel rods of fissionable material withdrawn from a heterogeneous (solid fuel) reactor to cool prior to reprocessing.
2. Gross fission products—atomic wastes recovered from reactor operation.
3. Separated fission products—specifically isolated constituents of reactor waste products.
4. Fission product gases, produced from nuclear fission in a homogeneous (liquid fuel) reactor.
5. Radioactive isotopes produced in reactor by neutron bombardment.

Each of the above potential sources has its advantages and limitations. Selection of the most appropriate one for any given processing line will no doubt depend on the dimensions and physical characteristics of the food being processed and the availability and economics of the source supply.

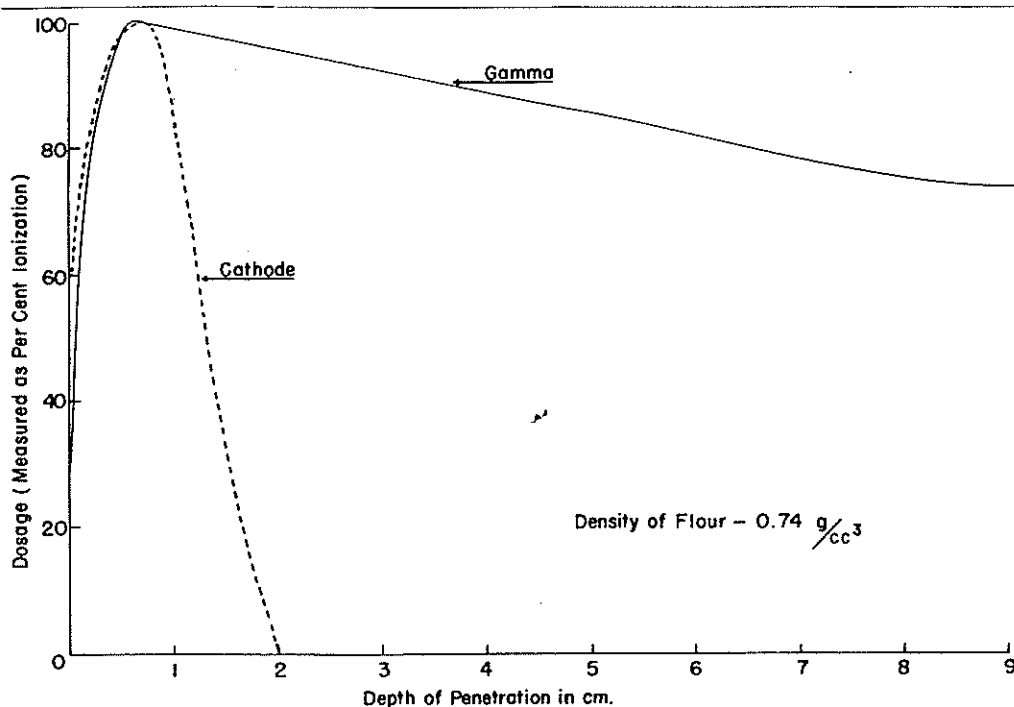
Reactor Fuel Elements. These elements, which are most widely used in our program today, have the major advantage of being relatively inexpensive. This assumption is based on the premise that the future atomic power program will provide an abundance of elements and that shipping costs can be satisfactorily resolved. The major limitation is non-uniformity of energy spectra and ma-

jor drop-off in activity with elapsed time.

Gross Fission Products. These have the same limitations as spent fuel elements, and here again some of the low-energy gammas may cause a considerable overdose on the surface of the product. In addition, considerable time and expense are involved in chemical separation and in attaining the required concentration. Their principal advantage over fuel elements is that they do not tie up the considerable inventory of expensive fuel.

Separated Fission Products. These offer the advantage of selecting a specific element with a known half-life (the time required for its initial intensity to be reduced by half) and a uniform energy spectrum. Cs^{137} appears to promise well in this respect, since it has high energy and a half-life of 30 years. Its principal disadvantages are the difficult separation process and limited availability. However, this situation should improve as separation technology develops and as more chemical processing plants are constructed.

A homogeneous reactor of the water boiler type could be designed, using fissionable material in solution, and the resulting gaseous products could be piped off and pumped through coils into the irradiation chamber. Since the principal active fission product gases (namely xenon,



krypton, and iodine) have half-lives of only 7 to 17 seconds, these gases must be removed rapidly. In addition, gamma rays produced from these gases will be accompanied by neutrons which are, of course, undesirable because of the possibility of their causing induced radioactivity, depending upon the specific item treated and the time of exposure. There is thus considerable engineering technology still to be developed in this field.

Induced radioactivity also crops up in the use of electron generators or high-energy gammas. Investigations are currently under way to determine what the maximum safety energy will be. This is of prime importance, since energy defines penetration. Current theoretical calculations indicate that energies up to a few Mev present no apparent problem. Electron energies of 10 to 15 Mev which can penetrate 3 to 5 inches also appear to be acceptable, but the safety of these figures must be confirmed by direct experimentation. Energies above 15 Mev may well pose problems with regard to induced activity. Fortunately, however, most food elements have high activation thresholds, and this induced activity should not constitute a serious biological hazard.

Isotopes. Turning now to isotopes produced in reactors by neutron bombardment, Co^{60} is currently in

wide use. It has a 5.27-year half-life and is of uniform energy. In addition, elements such as manganese and sodium, incorporated in a fluid to be passed through the core of the reactor or in the reactor coolant, have been suggested as sources of gamma radiation. Also, the fluid fuel of the reactor can be pumped from the core of a reactor to an external loop, providing a source of intense gamma energy. However, radioisotopes in megacurie quantities will be required for commercial units, and unless production reactors can be used, no such quantities will be available in the near future. The total amount of isotopes delivered in the past 8 years has been only 55,000 curies.

It is readily apparent, then, that there are many potential sources of gamma or electron radiation. Current work sponsored by the Department of the Army will aid in determining those forms which offer the best chance of success to the food processor.

The Problem of Food Acceptability

Undesirable Changes from High Radiation Dosages. Although development is still in its early stages, research clearly indicates that commercial sterility can be attained and that the process has potential for commercial adaptation. To attain sterility, doses of 1.5 to 4.0×10^6 rep¹ are required. Unfortunately, along with the drastic effect upon food spoilage microorganisms at these high dosages, subtle biochemical changes may alter color, odor, flavor, or texture. The chemical reactions responsible for alteration of flavor and odor are thought to be oxidative and reductive. Means have been devised to offset or diminish these undesirable effects through use of additives or free radical acceptors, or by changing the physical environment during irradiation. Obviously, until foods can be made fully acceptable, the advantages of "cold preservation" cannot be fully realized; therefore present efforts are being directed largely toward controlling these undesirable sensory changes. A number of items such as pork, pork sausage, bacon, sweet potatoes, Brussels sprouts, green beans,

chicken, beef liver, and halibut fillets have been able to withstand these high levels of irradiation without deleterious effects.

Mild Pasteurization Plus Refrigeration. In contrast to sterilizing radiation dosages and the undesirable changes caused by them, relatively low radio-pasteurization treatment can be given to many foods without altering acceptability. Such a process, utilizing 2–10% of sterilizing doses (50,000 to 500,000 rep), can reduce microorganisms 90–99%, and post-irradiation refrigeration can prevent the residual microbial population from reproducing. This type of treatment may have a significant impact upon the wholesaling and retailing of fresh prepackaged meats, since refrigerated shelf life after irradiation can be extended as much as five-fold. It may also reduce losses in fresh fruits and vegetables. Preliminary investigations indicate that certain highly perishable commodities such as strawberries, coleslaw, and lemons can have their shipping time and shelf life extended manifold by use of mild surface or pasteurization treatments.

In this category there seems to be a highly significant potential for the baking industry. Prepackaged baked and partially baked items such as "brown-and-serve" products, waffles, white bread, pound cake, and English muffins have been exposed to doses of 5×10^5 to 1×10^6 rep. Although acceptance ratings are often depressed at higher dosages, the items still score well into the acceptable range, and in many instances panel members cannot differentiate between irradiated and nonirradiated samples. Many such items have been held for months at room temperature, even the highly perishable waffle and English muffin, with only minor organoleptic changes. Changes in formulations may well provide the key for long-term unrefrigerated stability of certain irradiated prebaked or brown-and-serve-type bakery products (Figs. 5, 6, 7).

Potential Applications of Radiation

According to reports, at least 100 million pounds of bread are ruined by mold each year in bakeries and retail outlets. Mold damage to food products in general has been esti-

mated as costing more than a million dollars annually. Whereas chemical retardants merely slow down the growth of mold, ionizing radiation completely destroys it; and since relatively low doses are required, this should be a lucrative field for radiation.

In addition to low-dosage radio-pasteurization, attention is being focused on a relatively high pasteurization dose of approximately 1 megarep. Though not sufficient to preserve food indefinitely, this dose may prove adequate to appreciably prolong preservation of many foods. Certain highly perishable items so treated have been stored for many days without refrigeration, or for several weeks with refrigeration. Under this process, certain cooked or smoked meats, blanched vegetables, and other items in which enzymes have been inactivated could be packaged in heat-sealed flexible bags and stored for extended periods under refrigeration. If the product is of low acidity or low moisture content so that *Clostridium botulinum* is not a factor, storage may be maintained at room temperature.

Successful Uses of Radiation

The last dose range worthy of special consideration is that in which there is substantial evidence to indicate success—limited radiation doses of several thousand to 100,000 rep.

Delaying of Sprouting. Relatively low doses of 8,000 to 15,000 rep have effectively inhibited sprouting of onions and potatoes. In addition, reduced weight losses and lower respiration rate have been reported in long-term storage studies. This field appears to hold great promise and is of particular interest to the potato chipper.

Destruction of Food-Borne Helminth. A dose of 25,000 rep has been sufficient to break the cycle trichinosis caused by consumption of fresh pork infested with trichinae. Recently, eight other similar diseases caused by meat, fish, and poultry in different parts of the world have been cited as possibly being susceptible to control by irradiation of the host meat.

Deinfestation of Cereals, Grains, and Spices. Insect infestation of commercial cereal grains, cereal products, dried fruits, and military ration components made therefrom has for

¹ One rep (roentgen equivalent physical) is equivalent to the absorption of 93 ergs per gram of material of unit density.

Fig. 5. Rye bread: Irradiated Nov. 10, 1955; stored at room temperature for 2 months. Radiation source: Gamma (Facility Materials Testing Reactor). Photographed Jan. 10, 1956.

Fig. 6. Brown-'n-serve rolls: Irradiated October 5, 1955; stored at room temperature for 2 months. Radiation source: MTR (Gamma). Photographed December 10, 1955.

Fig. 7. Brown-'n-serve waffles: Irradiated October 5, 1955; stored at room temperature 2 months. Radiation source MTR (Gamma). Photographed December 10, 1955.

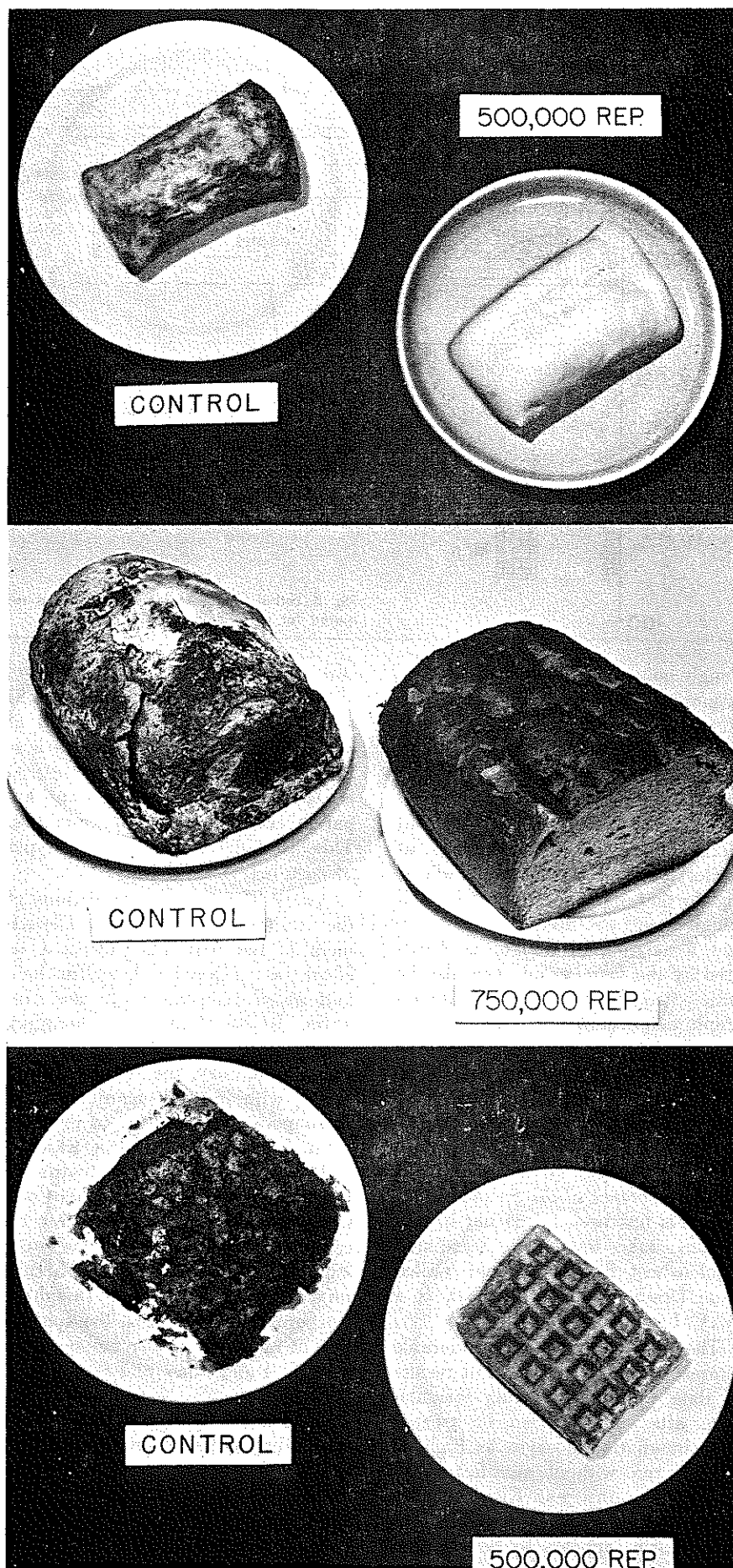
many years constituted a serious loss, costing more than \$300,000,000 annually. High-frequency heating, pressure, sonic treatment, centrifugation, and chemicals have been widely used, but the search continues for a new approach to this old problem.

Ionizing radiations have effectively destroyed the common grain-infesting insects in all four stages of life—egg, larva, pupa, and adult—at dosages far less than those required for bacteria, yeasts, and molds. The rate of destruction is dependent upon the dosage used—the higher the dosage, the more rapid the kill. Exposure to ionizing radiation in low doses of approximately 12,000 rep destroys insects in all forms within a few weeks. Dosages of 25,000 to 50,000 rep have prevented insects from reproducing and from developing to later metamorphic stages; higher dosages, in the range of 400,000 rep, are required to destroy the insects instantaneously (Fig. 8). Experiments sponsored by the QM Food & Container Institute indicate that in cereal ration bars, fruit ration bars, brownie mixes, and gingerbread mixes, irradiation to levels at or below 100,000 rep will not adversely affect sensory qualities and will destroy all forms of insect life. Cereal bars so treated have been successfully stored for 1 year at 100°F. without significant changes.

Respiratory activity in stored grains due to common fungi has been a significant cause of deterioration, and it appears that fungal respiration can be completely eliminated by treatment with ionizing radiation.

Current Indications and Investigations

As for physical tests of flours subjected to irradiation, the following general pattern can be anticipated.



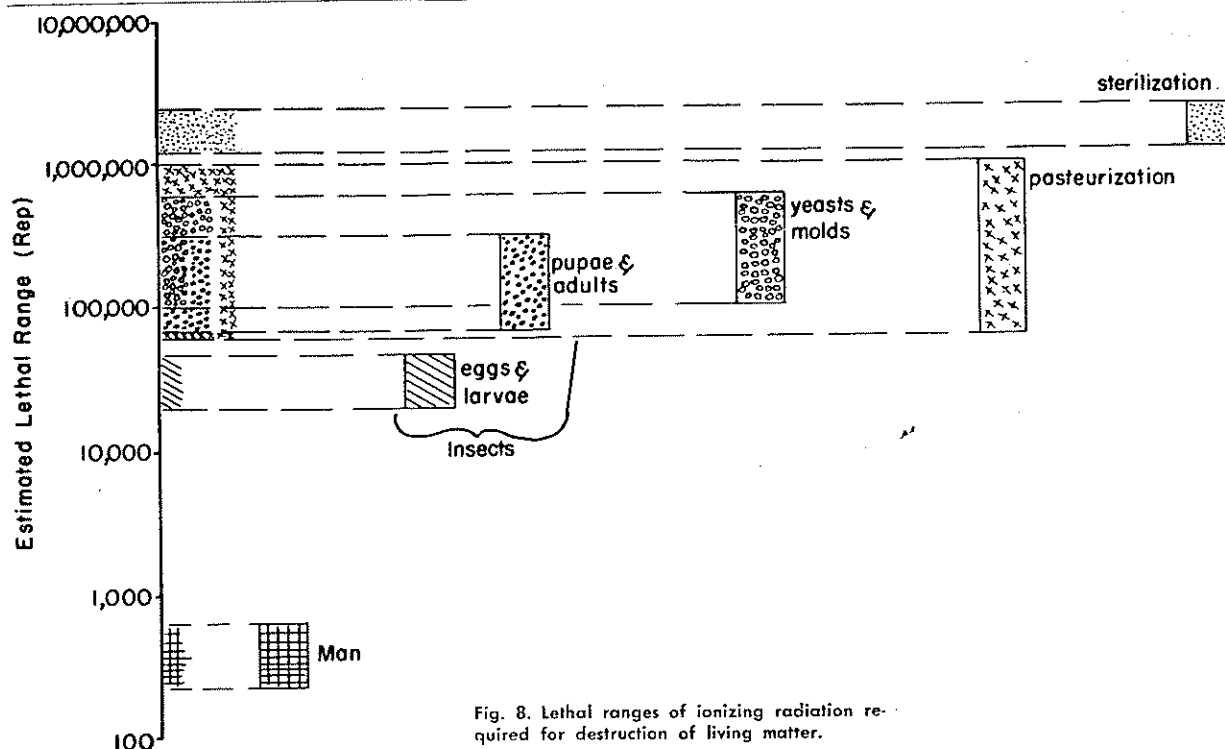


Fig. 8. Lethal ranges of ionizing radiation required for destruction of living matter.

Dough consistency, as measured by farinograph absorption, appears to decrease with irradiation; yet at very high dosages an increase is apparent. Dough development time decreases regularly with increased irradiation, indicating a protein degradation, and mixing tolerance also decreases at higher levels of irradiation, indicating further damage to protein and dough structure. Reduced elasticity and weakening of dough, as measured by the farinograph, can also be anticipated. With respect to amylograph determinations, high irradiation dosages appear to have a drastic effect upon viscosity. It should be emphasized, however, that these effects are pronounced only at higher dosages; *at lower levels of irradiation, the changes do not appear to affect acceptance of the finished product.* This has been borne out by numerous bake tests with irradiated whole-wheat flour and flour milled from irradiated Cornell wheat, at a level of 5×10^5 rep.

The Army has shown considerable interest in canned bread, and results to date indicate that this formulation, after baking, can be treated with irradiation dosages as high as 2×10^6 rep without significant organoleptic changes. Commercial bread, however, when irradiated in sliced form, appears to be changed

considerably above 250,000 rep.

Paste products such as macaroni and spaghetti have been treated at levels sufficient to destroy various forms and types of insects (100,000 rep), and here again there is no apparent effect upon sensory qualities. This also holds true for various types of corn cereal.

Aware of national implications of the radiation of food, the Department of the Army has directed its effort toward drawing American food and allied industries into the program. In the hope of stimulating closer teamwork between industry and the military, the Army is sponsoring with industry many ventures in cooperative research and development. Those now in effect which I feel are of special interest to the cereal industry are: Quaker Oats Company, the effect of irradiation on cereal products such as oats and corn; Pillsbury Mills, its effects upon cake mixes and batters; and Doughnut Corporation of America, the application of radiation to such commodities as waffles and other prebaked goods. Negotiations are under way with other industrial groups, and the Army hopes that its list of cooperators will be ever-increasing. (Interested organizations should contact the QM Food & Container Institute, Chicago.

The effects of radiation on germi-

nation of seeds and mutation in plants are now receiving a great deal of attention at national laboratories and agricultural experiment stations. Work at Brookhaven has indicated that when corn seeds were irradiated, results were variable: some offspring grew taller and others shorter than the parent plant; some matured earlier, others later.

Investigators are currently experimenting with rust-resistant strains of oats and wheat. Blight-resistant oats and windstorm-resistant rice are also being studied. By controlling temperature and oxygen levels during mutation processes, researchers feel that they may be able to "tailor" seeds to fit any specific set of conditions.

What Problems Still Lie Ahead?

Principally, an understanding must be reached of the mechanism responsible for loss in acceptability. This apparent loss varies considerably from commodity to commodity and is proportional to the amount of irradiation employed. Fortunately for cereal and allied industries, dosages required will for the most part be relatively small, and this has proved to be a great asset. Once the mechanism of these changes is understood, control methods will have to be devised.

Much work is necessary to deter-

mine further exact dosages for commercial sterility, especially where food poisoning or intoxication is a factor.

The effect of irradiation on enzymes must be thoroughly investigated. It is now known that dosages of 5 to 10 times the amount required for sterilization are necessary for complete inactivation of enzymes. Yet in some cases sterility dosages appear to reduce enzymes to a dormant state without fully destroying them. Here again, the effect varies with the enzyme being treated.

As to packaging, work is needed on both rigid and plastic-type containers. The effect on enamel and sealing compounds in rigid containers must be determined, and physical characteristics of films must be investigated. The state of the art, as it is known today, seems to indicate that common packaging films are not significantly altered at the dosage levels of commercial sterility. At low levels for insect control there should be no undesirable effects, except for some slight discoloration of certain films.

Further investigations are needed to determine storage characteristics of irradiated foods at elevated, room, and refrigerated temperatures.

The entire field of radiation source availability requires further emphasis—to design and develop necessary equipment for both electron and gamma irradiation facilities. Considerable attention must also be devoted to dosage measurement and distribution.

Foods treated by ionizing radiations must be shown to be safe and wholesome when fed in large amounts over long periods of time. The Quartermaster Corps in close cooperation with the Office of the Surgeon General of the Army and the Food and Drug Administration, has developed a comprehensive and extensive program to provide this information. Animal feeding studies involving subacute and chronic ailments, and studies in human metabolism have been under way for some 18 months now and, to date, there has been no concrete evidence of toxic effects. Further, the program's first long-term feeding project is now under way: 70,000 pounds of potatoes were irradiated recently with 15,000 to

30,000 rep, for studies on long-term feeding and economic feasibility.

As for macro and micro nutrients, the degradation caused by irradiation does not appear to be greater than that associated with conventional processing techniques. Of the vitamins of specific interest to the cereal industry, thiamine appears to be most sensitive to irradiation, riboflavin more resistant, and niacin quite stable. Here again, vitamin losses will be sharply reduced at low levels of irradiation.

And finally, the process of using ionizing radiation must be shown to be economically feasible. Cost estimates today are hypothetical, since there are no proved costs of irradiation equipment of the type required by large-scale commercial production. Many persons have ventured estimates along this line, and the consensus would indicate the following ranges:

Sterilization (based on 2×10^6 rep)	
Cathode ray generator	per lb. 1-5 c
Linear accelerators	0.3-2.5c
Gamma irradiation	
Reactors	1.5-7 c
Isotopes	3-10 c
Inhibition of Sprouting (based on 10,000 rep)	
Linear accelerators	per ton \$0.14-1.00
Fission products	\$3.50-5.00
Reactor	\$1.30
Deinfestation (based on 30,000 rep)	
Linear accelerator	\$0.10-0.74
Reactor	\$1.00

It should be reiterated that the figures just indicated are based on many assumptions and forecasts. More accurate economic analysis will depend upon the actual pilot-plant runs which the Quartermaster Corps plans to undertake, utilizing new facilities for food preservation, to be constructed by the Department of the Army in conjunction with the Atomic Energy Commission. This pilot plant, capable of treating 1,000 tons a month with 2×10^6 rep, was announced by the President in his recent budget message to Congress and is expected to be ready by the close of 1958. Capacities for current sources are indicated in Fig. 9.

This report has presented a synopsis of the current status of the radiation program and, it is hoped, some insight into future problems. There are more corners to turn and more bridges to cross before a commercial process is realized. However, irradiation of cereals and grains may well be one of the early "break-throughs" in the program. Already it appears that fungal respiration, a significant cause of deterioration in stored grain, can be completely eliminated by treatment with ionizing radiation. With close teamwork of an extensive military-academic-industrial network, radiation may be added as a third dimension to the food processing industry.

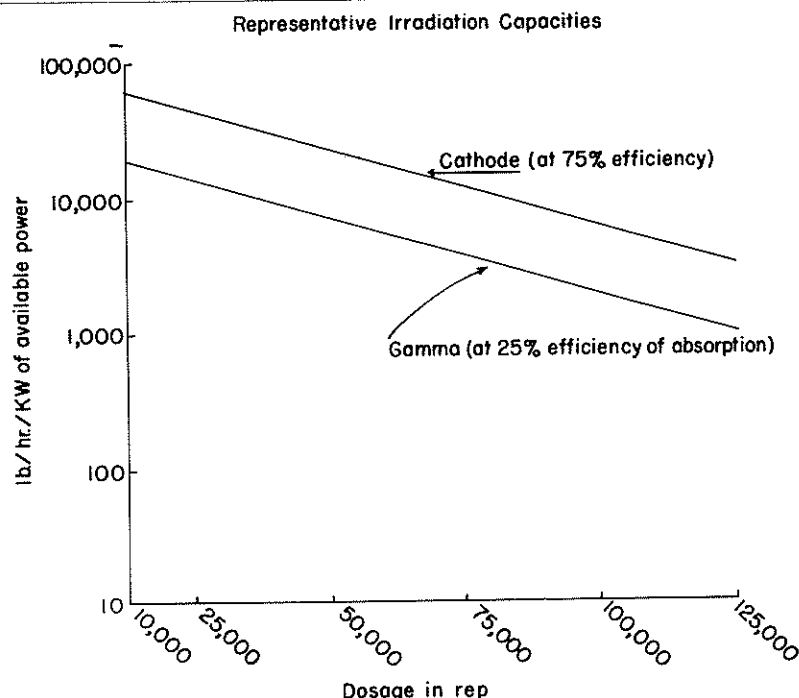


Fig. 9. Representative irradiation capacities.